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2D AND 3D DATA PROCESSING OF ARCHAEO-MAGNETIC DATA

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Introduction. The Sabine Necropolis at *Colle del Forno* (700-300 B.C.) at Montelibretti, Rome is characterized by *dromos* chamber tombs, most of them unexplored till now. The tombs can be assimilated to cavities of a standard volume of some cubic meters; the entrance of the tombs is a corridor 6 m long with a 1 square meter section . The surficial geology of the area consists of a series of tuffs about 10 m thick overlying Pleistocene-Quaternary sandy-clayey sediments. A thin layer of top soil (20 - 30 cm) covers the tuff. The investigation of the Necropolis in the past decade has been performed by different geophysical methodologies: electrical, electromagnetic and magnetic methods have been widely adopted to investigate several chamber tombs (Piro et al, 2001). The aim of this paper is to analyze an integrated approach to the processing of magnetic survey data. The magnetic susceptibility contrast between topsoil, subsoil and rocks (topsoil is normally more magnetic than subsoil) permits to detect ditches, pits and other silted-up features that were excavated and then silted or back-filled with topsoil. Meanwhile back-filled areas produce positive anomalies, less magnetic material introduced into topsoil, including many kinds of masonry (for example, limestone walls) may produce negative anomalies of the order of some nanoteslas. The same behavior is related to the presence of cultural voids and tombs whose magnetic anomaly is generated by the lack of magnetic materials due to the cavities of the tombs. In the area a diffused magnetisation is manly due to the presence of top soil and tuff materials and high negative susceptibility contrasts can be expected because of the presence of the tombs. The magnetic survey was performed along a regular grid of 0.5 m x 0.5 m using a optical pumped Caesium-vapour magnetometer G858 (Geometrics), in the gradient configuration, on an area which is well known as far as the presence, size and position of tombs are concerned.

Methods. We analyzed the effectiveness of several methods for interpreting magnetic data and the possible synergies among the information obtained by each method. The approach is based on a preliminary evaluation of the depth of the causative body according to the solution of Euler's equation (Thompson, 1982); the refinement of the solution can be obtained by the interpretation of 3D analytic signal (Nabighian, 1972); the application of two-dimensional cross-correlation technique (Brizzolari et al., 1993, Piro et al., 1998) permits to estimate the spatial orientation, the shape and the susceptibility contrast of the causative bodies. The preliminary interpretation allows one to determine the starting model and to introduce the necessary constraints (e.g. susceptibility contrast, maximum depth of the magnetic targets) for the subsequent 3D modeling and inversion (Li and Oldenburg, 1996).

Results. The solutions of 2D Euler's equation were derived for all the South-North profiles of the selected area; the interpretation was carried out using different structural index (N=1.5-2.0-2.5-3) to verify the best result on the basis of the clustering of the solutions. A good clustering was obtained using the structural index N=2-2.5, which can be related to a target horizontally elongated. The use of order 1 (gradient and the gradient derivatives) of the Euler's equation permits to obtain a good compromise between the capability of the method to enhance shallow features without increasing the noise level. Furthermore, the relationship between the distance and size of the causative bodies (tombs), the window size with respect to the wavelength of the anomalies and the structural index should be considered to define the actual physical meanings of the structural index itself. However, the Euler's solution confirmed the presence of two main magnetic causative bodies located at a depth between 1.5-2.0 meters. The spatial position of the tombs appears well centered with the results of the analytic signal (Figure 1).

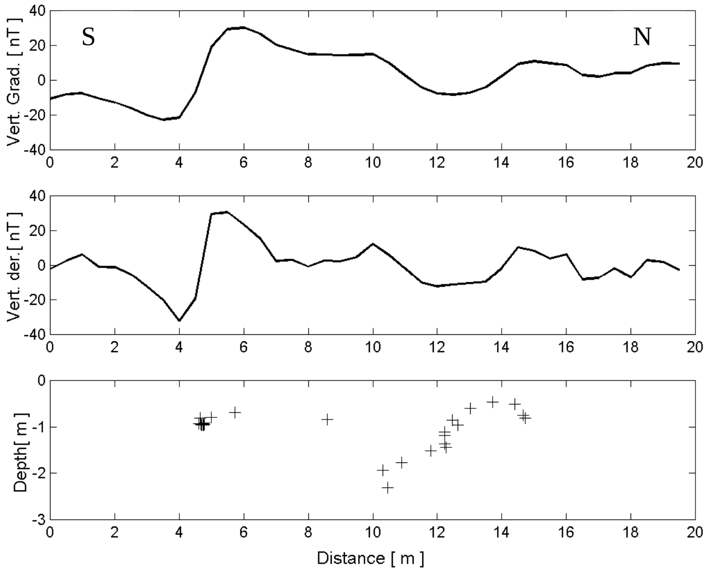

Figure 1: (top) profile of vertical component of the total magnetic field (x=4.5 m); (middle) vertical derivative of the vertical component of the total magnetic field; (bottom) solutions of the Euler' deconvolution for a structural index of 2.5.

To perform the cross-correlation analysis, different synthetic models were generated using a susceptibility contrast in the range between –0.003 and –0.007 S.I. units; the depth range of the

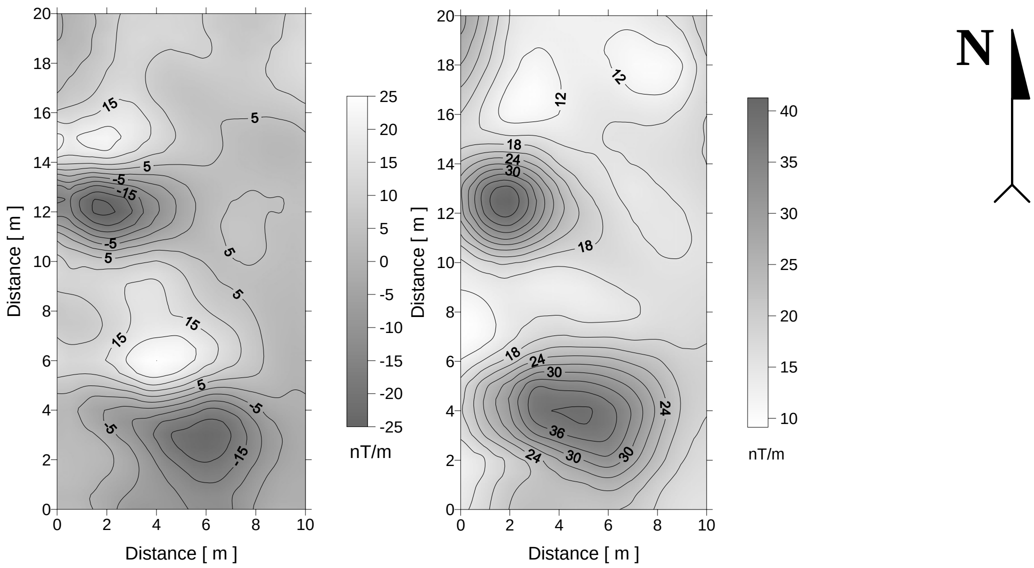

Figure 2: map of the amplitude of the analytic signal (left); results of cross correlation analysis on the vertical gradient of the total field (right), using a synthetic magnetic anomaly of a cubic model (1 m), with the top of the target at a depth of 1 m and susceptibility contrast –0.006 S.I. units.

model was determined according to the results obtained by the previous methods. The analysis of the compute correlograms shows that a set of theoretical anomalies due to an elementary cube-shaped body (each on sized 1 × 1 × 1 grid unit) works in a satisfactory way. The normalization of the cross-correlated data with respect to the maximum values of the auto-correlation of the different synthetic anomalies can help to limit the depth-range of the solution. The best matching between synthetic and experimental data was obtained for a depth of the top of the anomalous body d = 1 m and susceptibility contrast of –0.006 S.I. units (Fig.2).

In order to better delineate the main features (position, size, depth and shape) of the anomalous bodies we performed a 3D inversion of data using the MAG3DINV software (Li and Oldenburg, 1996). This software splits into prisms the subsoil, calculates the sensitivity function of each prism on each measuring point, finds the susceptibility distribution (constant within each prism) which (with respect to some user-chosen parameters, each one with its own weight) minimises a kind of χ^2 distance between calculated and experimental data. Originally it was thought to be employed mainly in large scale exploration data processing and performs the inversion of the total magnetic field anomaly (TMF) while in our case study, as in many archaeo-magnetic prospecting, the most common and reliable data are collected as vertical gradient of TMF. However synthetic simulations showed that, for shallow dipoles and low sensors, the main features (overall signal shape, maximum position) of the TMF profiles could also be found in the gradient profiles. Actually more than gradient measurements, in archaeological surveys, one should perhaps refer to "difference measurements" in as much as the distance between the two sensors is comparable to the distance from the bottom sensor to the anomalous body. In such conditions the anomaly wavelength is a few times larger than the distance between the two sensors. The main differences between TMF and "difference" profiles are (for these latter data): a decrease of the anomaly intensity, a slight increase in higher frequency and a fairly similar roll-off of the profile power spectra. The MAG3DINV input parameters too had to be carefully chosen with regard to our particular problem. For instance the software does not allow for negative susceptibility contrasts and we had to add 180° to the Earth Magnetic Field (EMF) inclination, virtually moving to the South hemisphere. The bodies result in "onion-like" structures, as far as the magnetic susceptibility contrasts are concerned (Fig. 3): the absolute susceptibility contrasts grow roughly from 0.003 to 0.007 (S.I) going into the core of the body. This smearing of the results does not allow for a precise definition of the body boundaries but nevertheless a delineation of the body shape is possible (Figure 4).

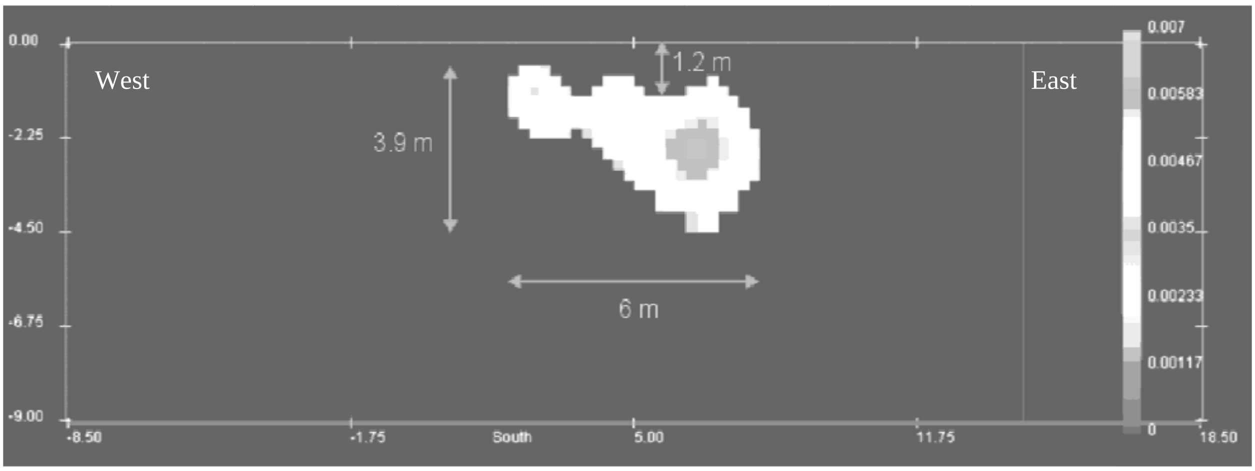

Figure 3 : Vertical axial section of the larger resulting body. Dimensions are referred to the iso-surface contouring the 0.003 (S.I.) susceptibility contrast volumes. The smearing overestimate the actual body boundaries which however are inside the evidenced volume (see text). It is also possible to see the "dromos", on the left.

Conclusion. The excavation of the area close to the southern anomaly pointed out a single corridor (dromos) with prismatic shape and section of 1 m x 1 m the depth of the top of the structure is at 1 m below the surface. The overlap of the topography of the dromos and the analytic signal map and the cross-correlation result show an good coherence.
The analytic signal method allowed us to calibrate the response of the interpretation of the Euler's equation; in the selected site, the 3D analytic signal well represents the projection on the surface of the shape and position of the tombs. The solutions of analytic signal and Euler's equation provide for a support of the first trial for the cross-correlation analysis or for subsequent 2D and 3D inversions.

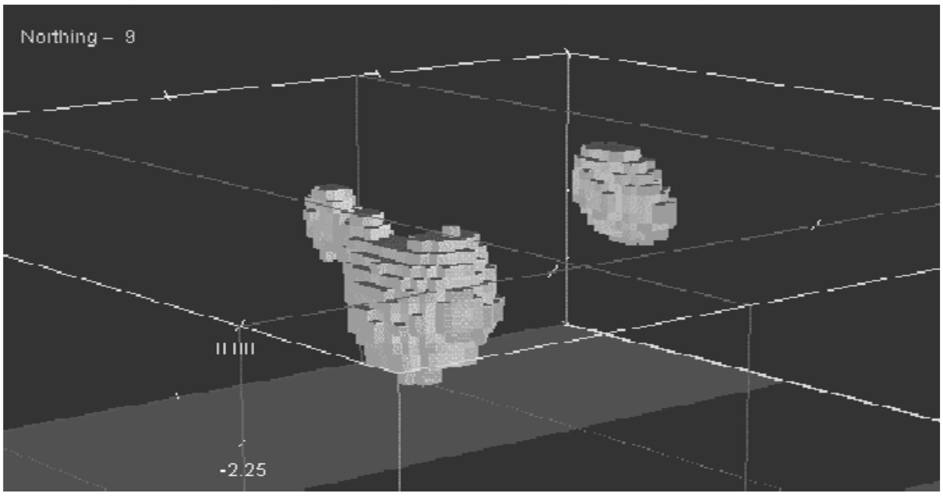

Figure 4 : Perspective view of the resulting bodies as seen from South-East.

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TOPIC: Processing, interpretation and visualisation of prospection data
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